CASUS
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DSECOP280: Automated Object Detection

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Uniwersytet Wrocławski

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Goals

Goals

- Relevant course: Introductory Classical Mechanics Lab Courses (also relevant Advanced Labs)

- Physics goals:
  - Basic numerical methods
  - Experiment setup
  - Dealing with noise

- Machine learning goals:
  - Introduction to Computer Vision (CV) from scratch
  - Application of CV for analyzing experiments

Structure

Structure

- Prerequisites:
  - Basic classical mechanics (already satisfied by being in lab)
  - numpy and `matplotlib`

- Lesson 1: Representation and manipulation of images in Python
- Lesson 2: Object tracking from scratch
- Lesson 3: Ready-to-use code for lab videos

- Components:
  - In-built interactive demonstrations and exercises
  - Mini-projects
  - In-lab use

Submodules

Lesson 1

Introduction to CV
(and manipulation using Linear Algebra)

```
[[1., 1., 1., 1., 1., 1., 1., 0., 1., 1., 1., 1., 1., 1., 1.],
[1., 1., 1., 1., 0., 0., 0., 1., 0., 0., 0., 1., 1., 1., 1.],
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[1., 1., 1., 1., 1., 1., 1., 0., 1., 1., 1., 1., 1., 1., 1.]]
```

Array representation

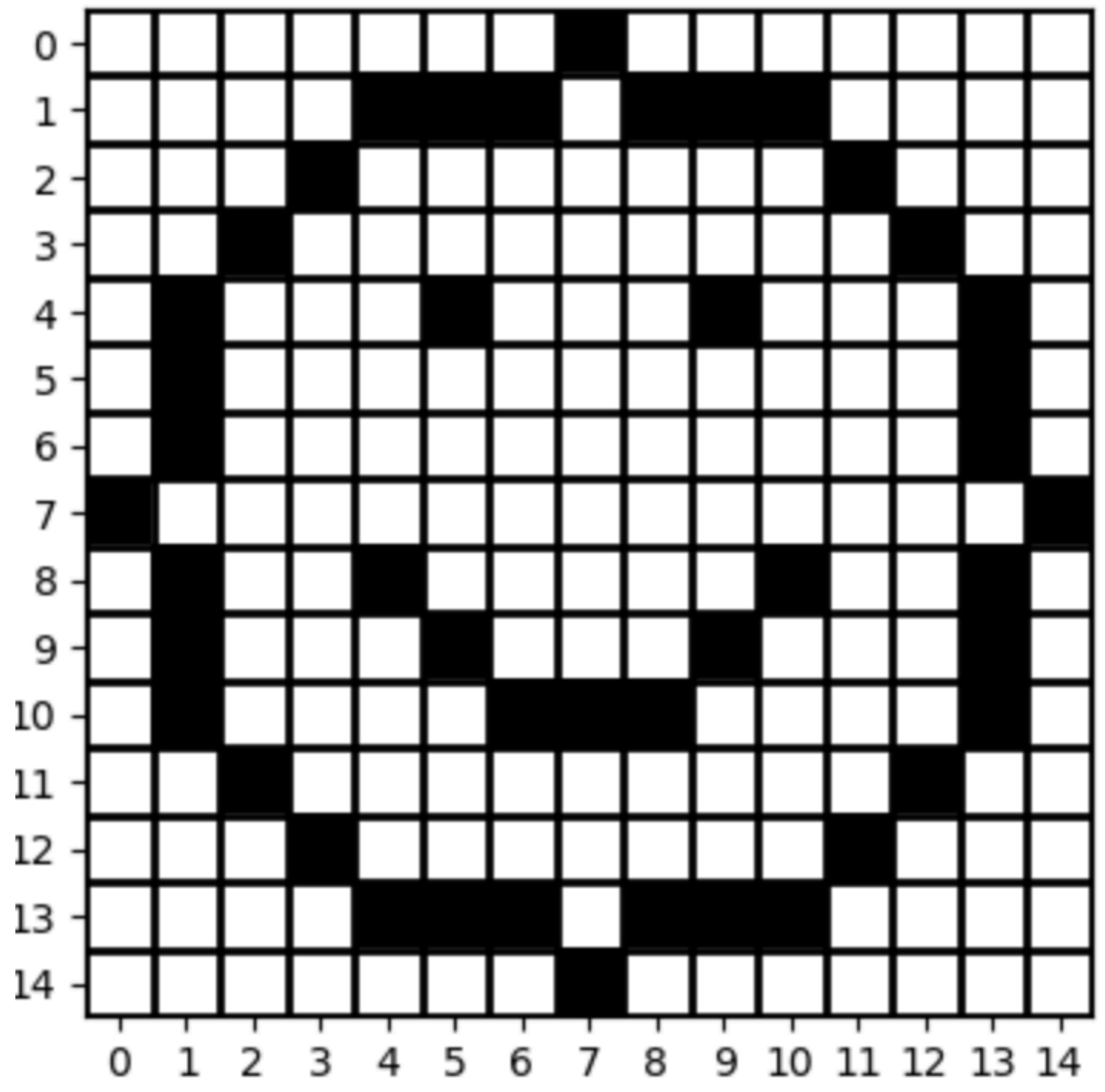
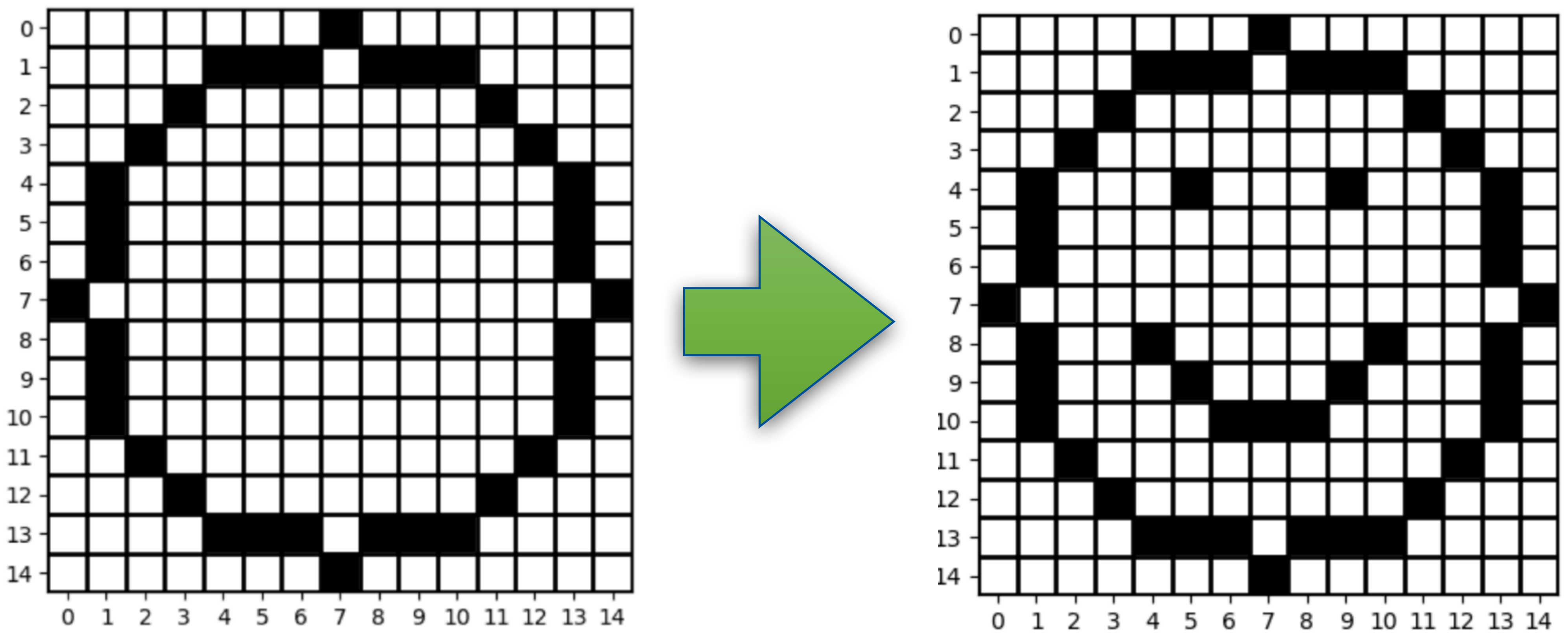


Image representation

Lesson 1

Introduction to CV - Pixel art warmup

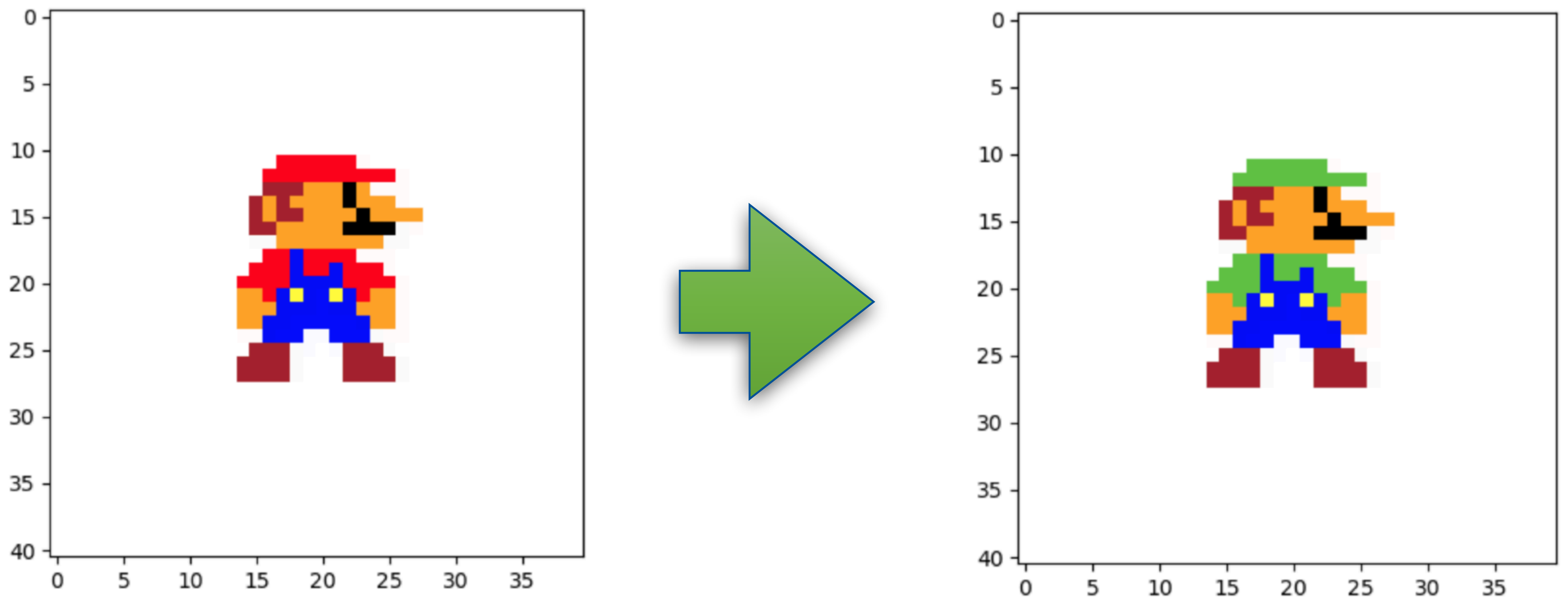


Manipulate pixels

```
# Define the positions of the eyes and the smile. Student code:
eye1 = (4, 5)
eye2 = (4, 9)


# Set these positions to 0 (black). Student code:
image[eye1] = 0
image[eye2] = 0

# Fill in the smile. Student code:
image[(10,7)] = 0
for i in range(1,4):
    image[(10-i+1, 7-i)] = 0
    image[(10-i+1, 7+i)] = 0
```

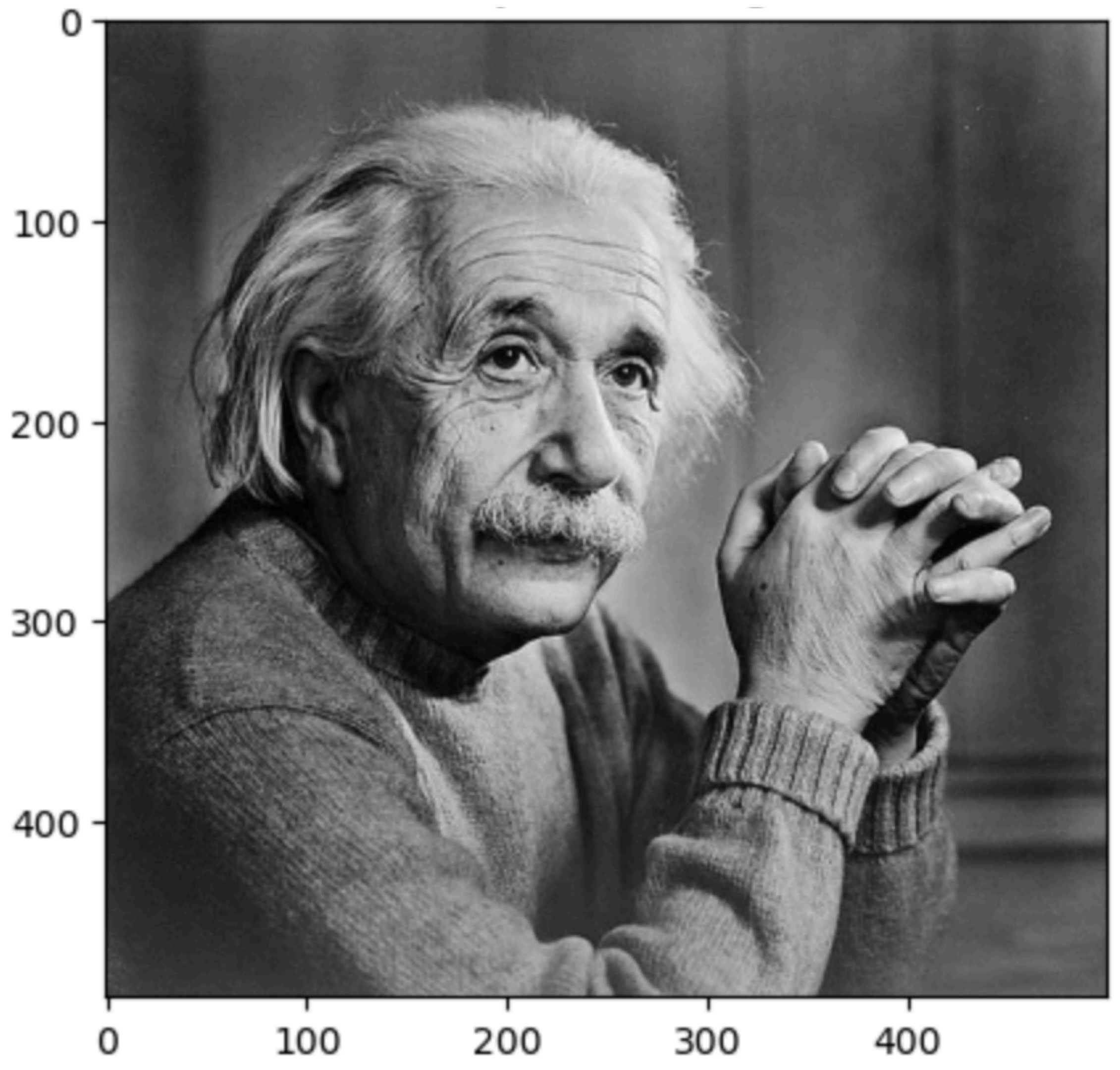


Manipulate pixel colors

```
# Fill in the code snippets, hints in comments:
# Pick a pixel.
hat_pixel = (11,18)
# Get pixel color.
mario_red = mario_image[hat_pixel][:]
# Set Luigi pixel color.
luigi_green = [96, 196, 69]
luigi_image = mario_image
# Select all red pixels, all three channels.
r_mask = mario_image[:,:,0] == mario_red[0]
g_mask = mario_image[:,:,1] == mario_red[1]
b_mask = mario_image[:,:,2] == mario_red[2]
# Combine the masks.
combined_mask = r_mask & g_mask & b_mask
# Change red pixels to green.
luigi_image[combined_mask] = luigi_green
```

Lesson 1

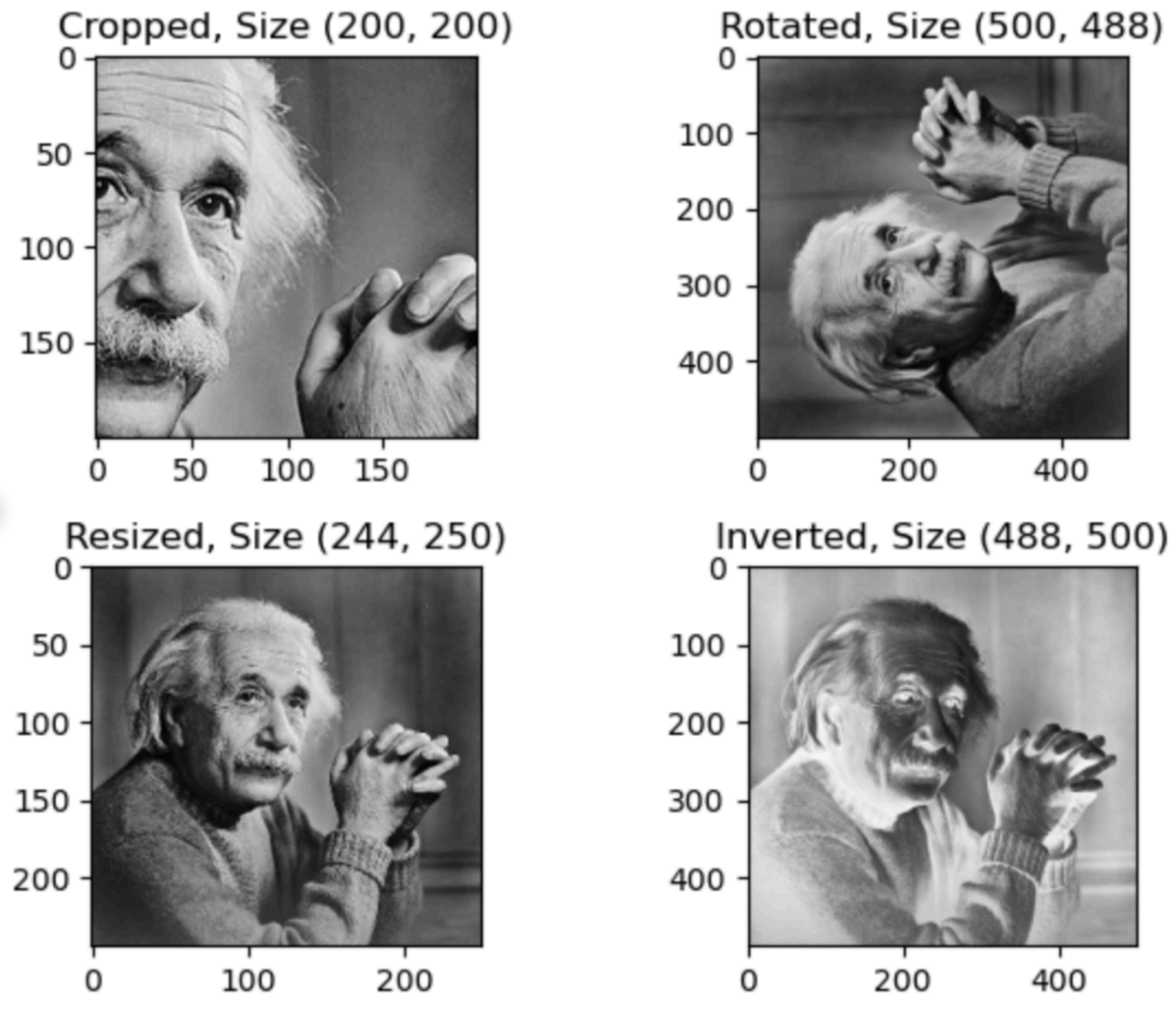
Introduction to CV - Basic manipulations



Input image

```
# Fill in the following lines:
# Cropping
cropped_image = bw_image[100:300, 200:400]
# Rotation (90 degrees)
rotated_image = np.rot90(bw_image)
# Resize
resized_image = bw_image[::2, ::2]
# Invert
inverted_image = np.abs(255 - bw_image)
```

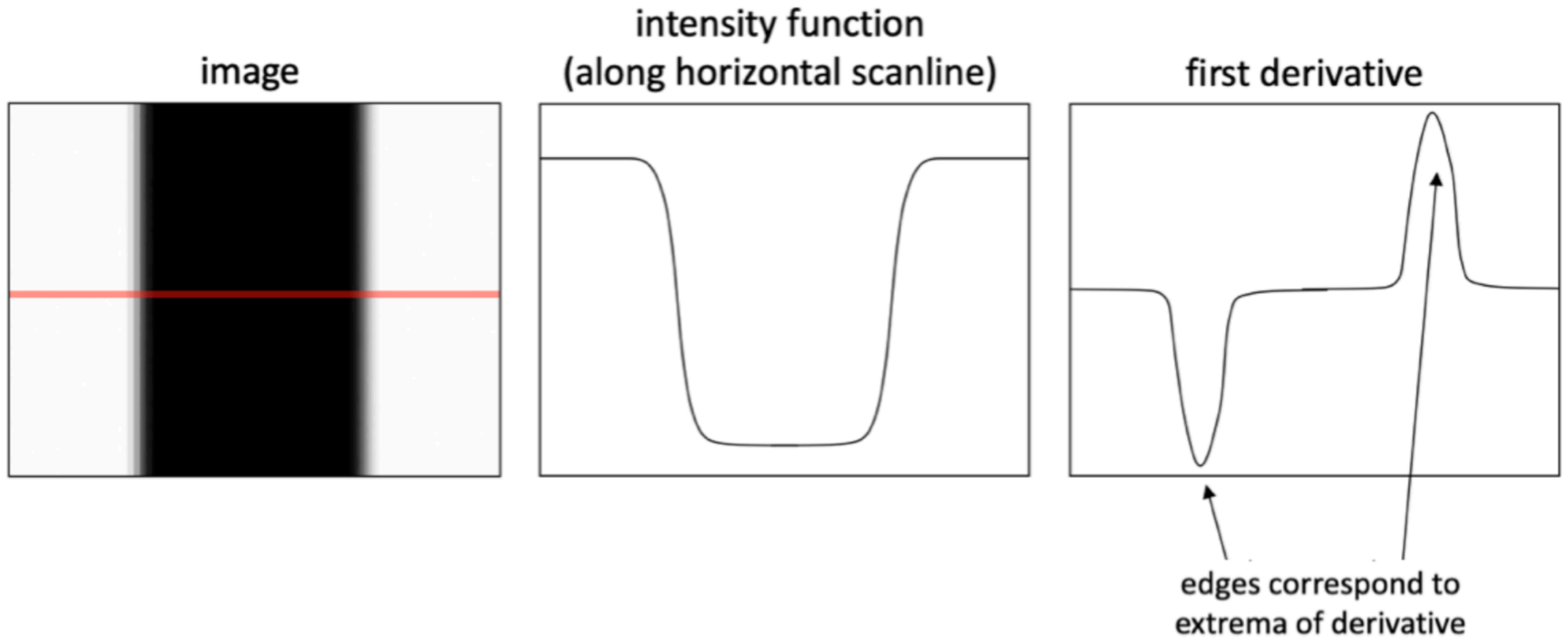
Student code



Basic manipulations

Lesson 1

Introduction to CV - Kernels and Convolutions - Example: Edge Detection



Build intuition

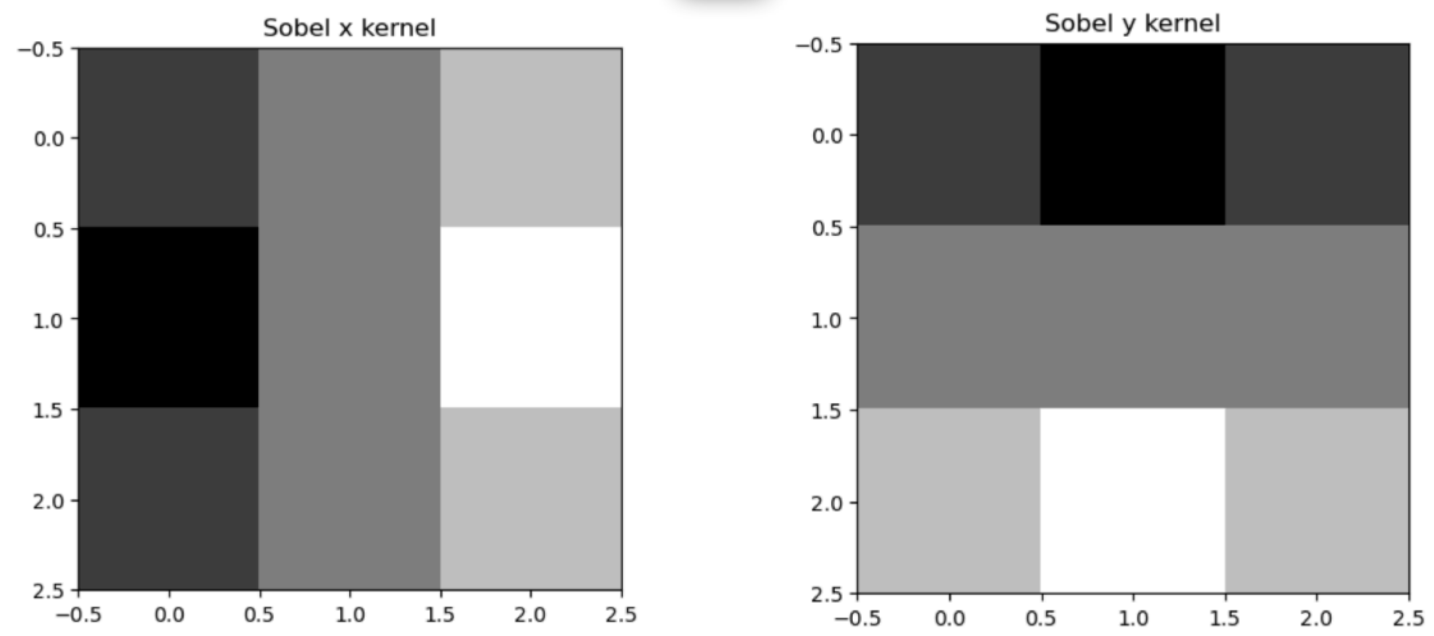
$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \quad S_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Operator definition

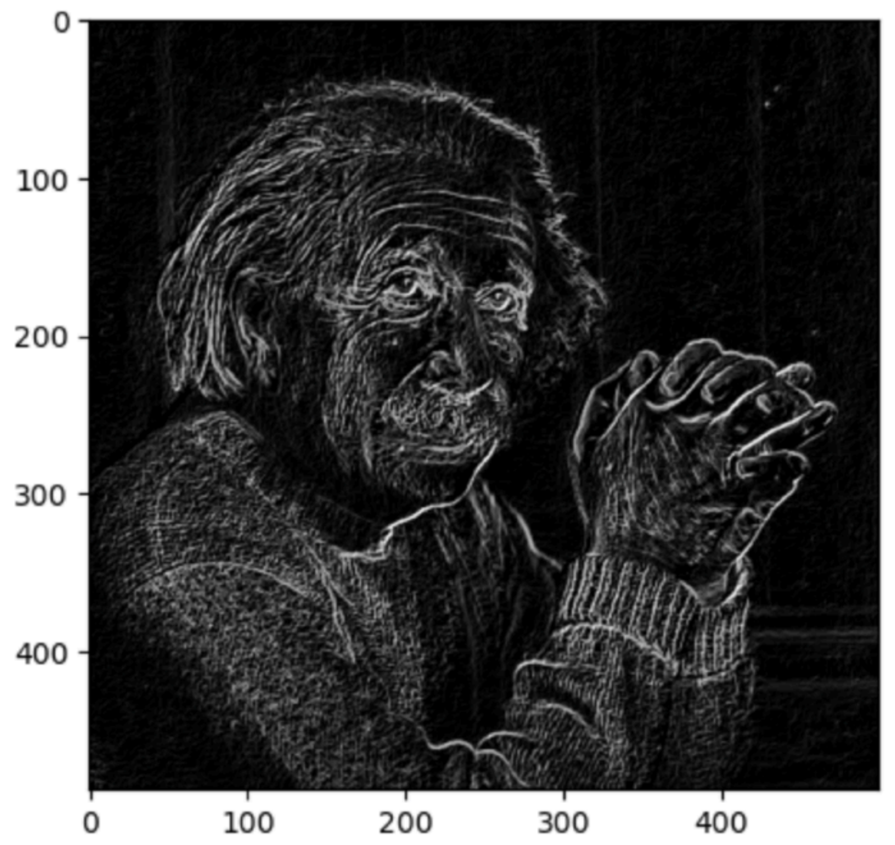
```python
def sobel_operator(image):
# Fill in the operators. Student code:
    sobel_x = np.array([[-1, 0, 1],
                        [-2, 0, 2],
                        [-1, 0, 1]])
    sobel_y = np.array([[-1, -2, -1],
                        [0, 0, 0],
                        [1, 2, 1]])
# End student code.
    grad_x = cv2.filter2D(image, -1, sobel_x)
    grad_y = cv2.filter2D(image, -1, sobel_y)

    grad_x = rescale(grad_x)
    grad_y = rescale(grad_y)
    return grad_x, grad_y
```

Student code (boilerplate provided)



Visualize kernels



Results

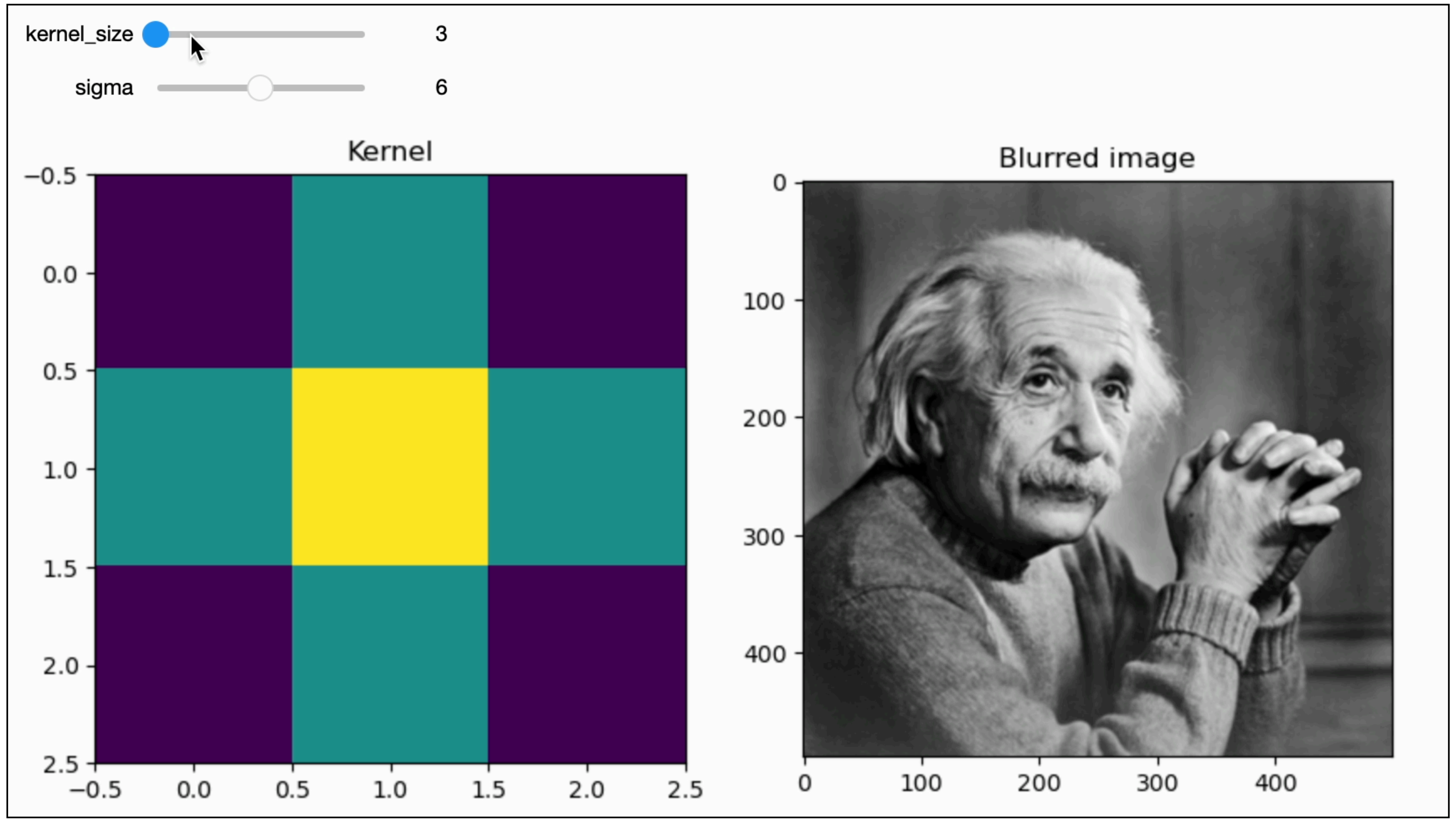
Lesson 1

Introduction to CV - Kernels and Convolutions - Example: Gaussian blur

Implement 2D Gaussian blur:

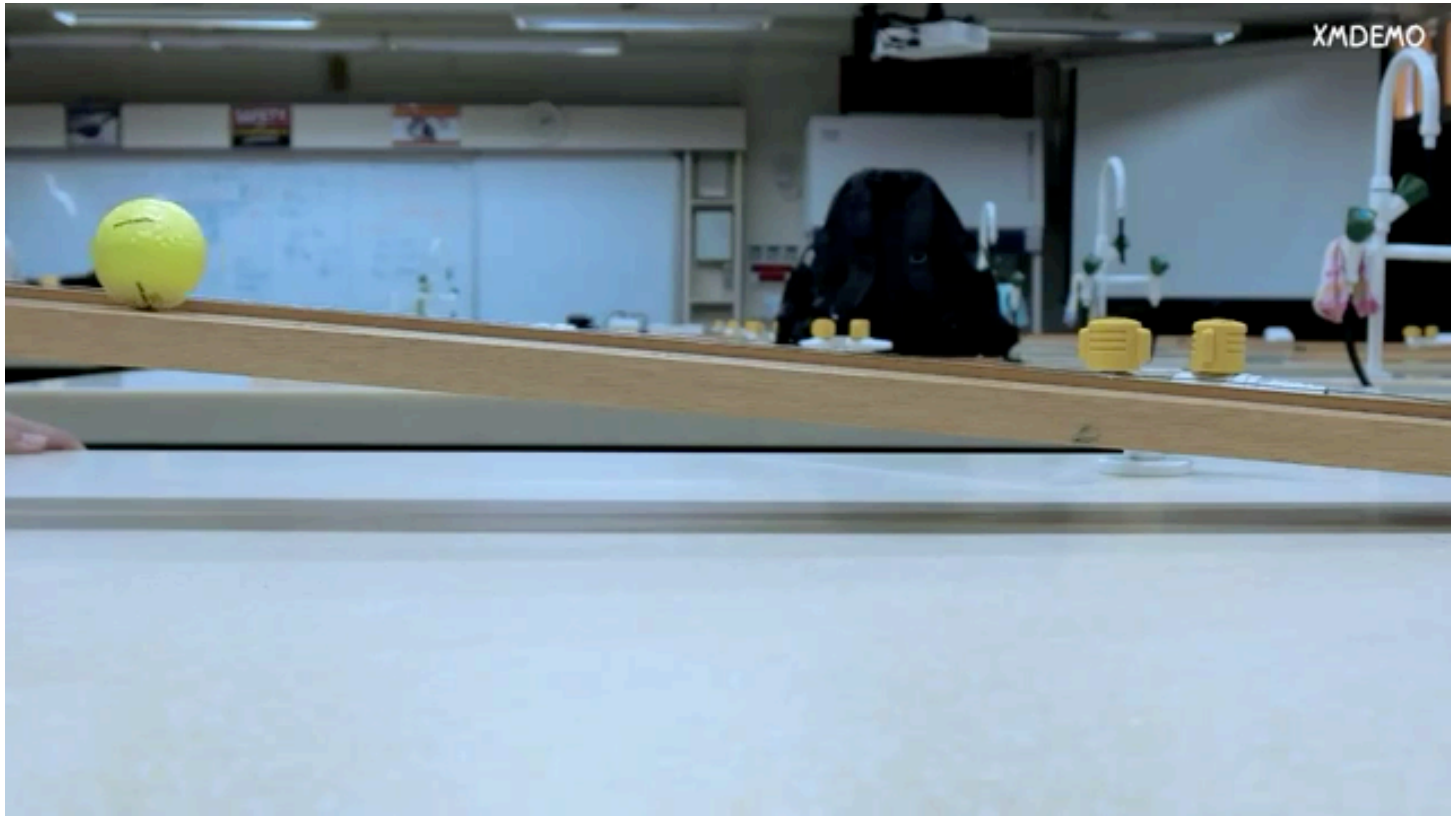
$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

```
def gaussian_blur(kernel_size=20, sigma=5, ret = False):
    ax = np.arange(-kernel_size // 2 + 1., kernel_size // 2 + 1.)
    xx, yy = np.meshgrid(ax, ax)
    # Student code:
    kernel = np.exp(-(xx**2 + yy**2) / (2. * sigma**2))
    kernel = kernel / np.sum(kernel)
    # End student code
    blurred_image = cv2.filter2D(image, -1, kernel)
```



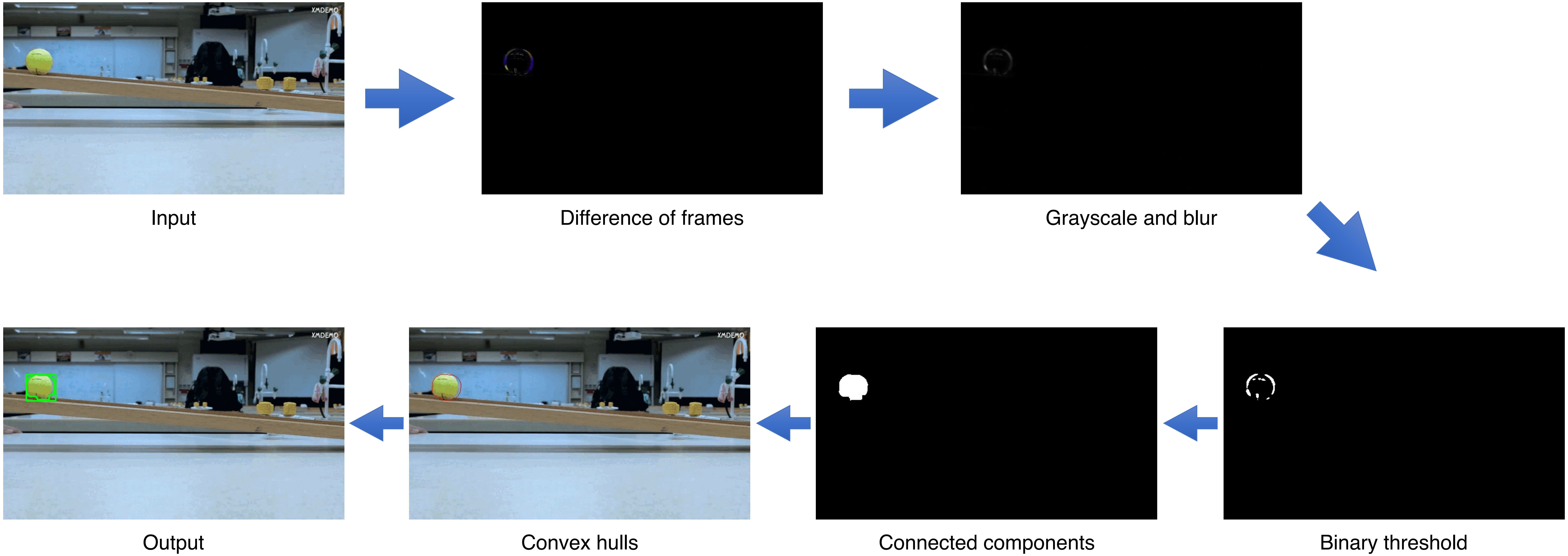
Lesson 2

Object tracking



Example experiment video

Object tracking - Simple algorithm with OpenCV operations



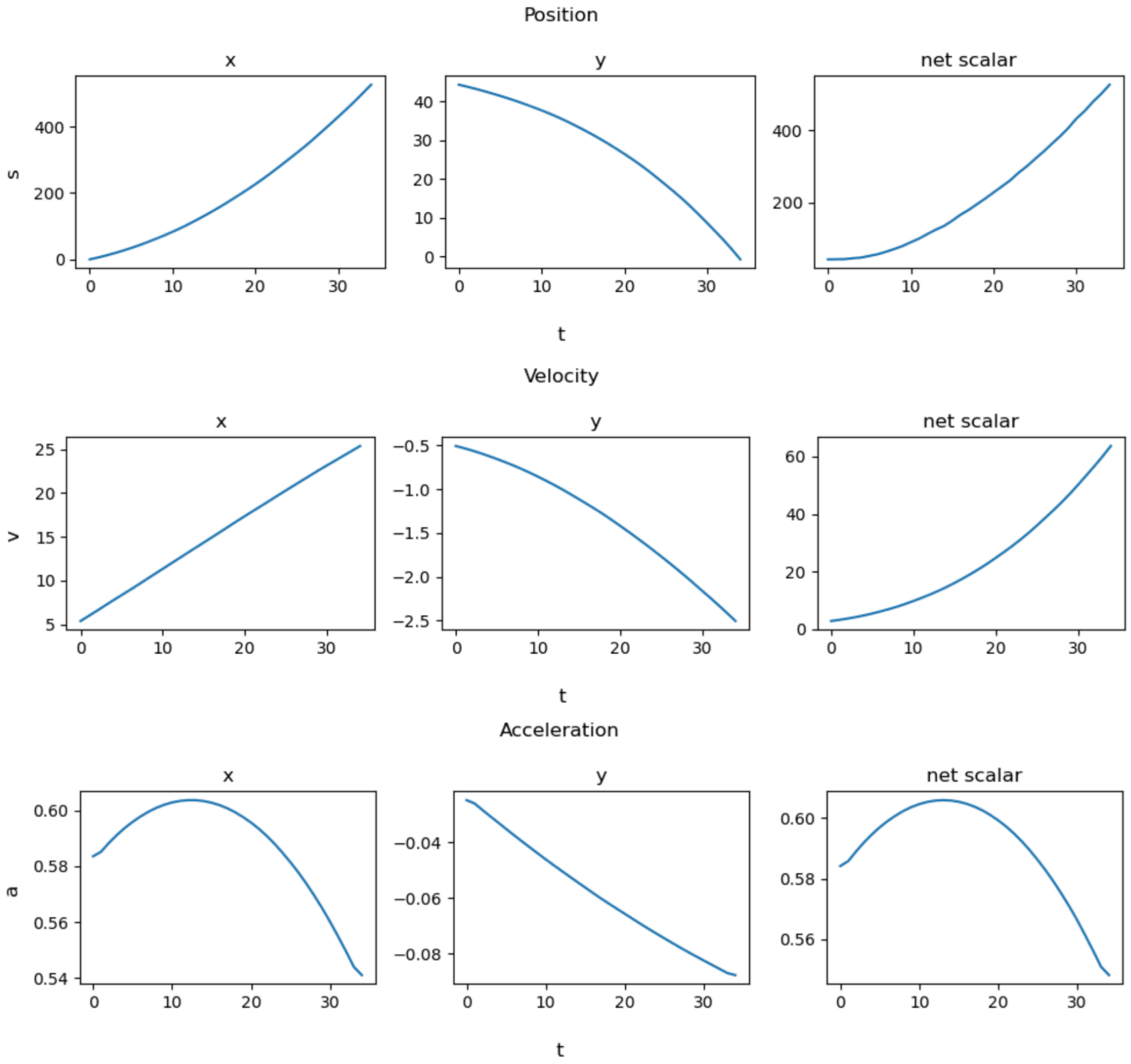
Lesson 2

Trajectory estimation

- Filtering noise
- Gradient calculation

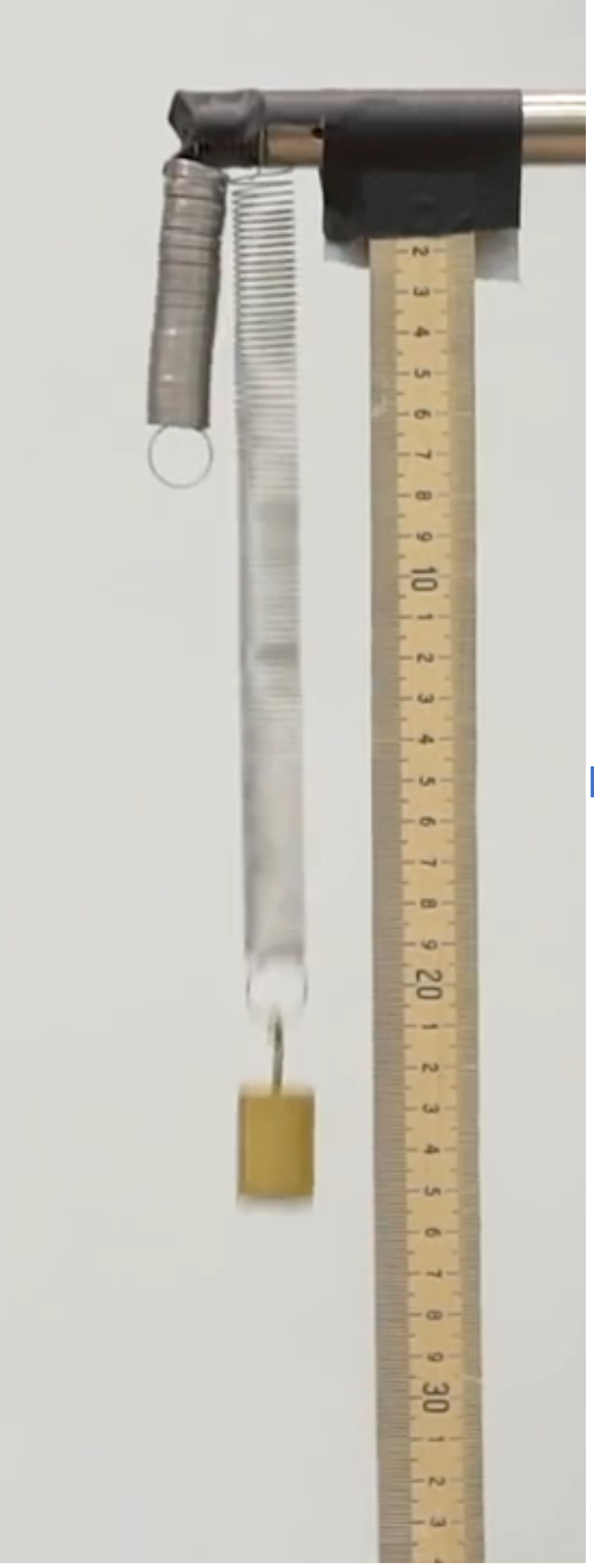
```
i=0 | Coords: x=43, y=88, w=55, h=49 | Detections: 1
i=1 | Coords: x=47, y=88, w=56, h=51 | Detections: 1
i=2 | Coords: x=52, y=88, w=55, h=51 | Detections: 1
i=3 | Coords: x=57, y=88, w=56, h=52 | Detections: 1
i=4 | Coords: x=64, y=89, w=56, h=51 | Detections: 1
i=5 | Coords: x=71, y=89, w=56, h=53 | Detections: 1
i=6 | Coords: x=77, y=90, w=58, h=52 | Detections: 1
i=7 | Coords: x=85, y=90, w=59, h=54 | Detections: 1
i=8 | Coords: x=93, y=91, w=60, h=53 | Detections: 1
```

Sample output



Trajectory extracted from the example.

Automatic Tracking



Input video

```
python 03_auto_tracking.py spring
spring
Found directory spring. Moving there.
[INFO] Read video file in spring
Detection mode:
1. Manual Region of Interest Selection
2.  Automatic using YOLO
(Default 1)1
[INFO] Detection mode 1
[INFO] Manual detection
Select a ROI and then press SPACE or ENTER button!
```

Run provided code

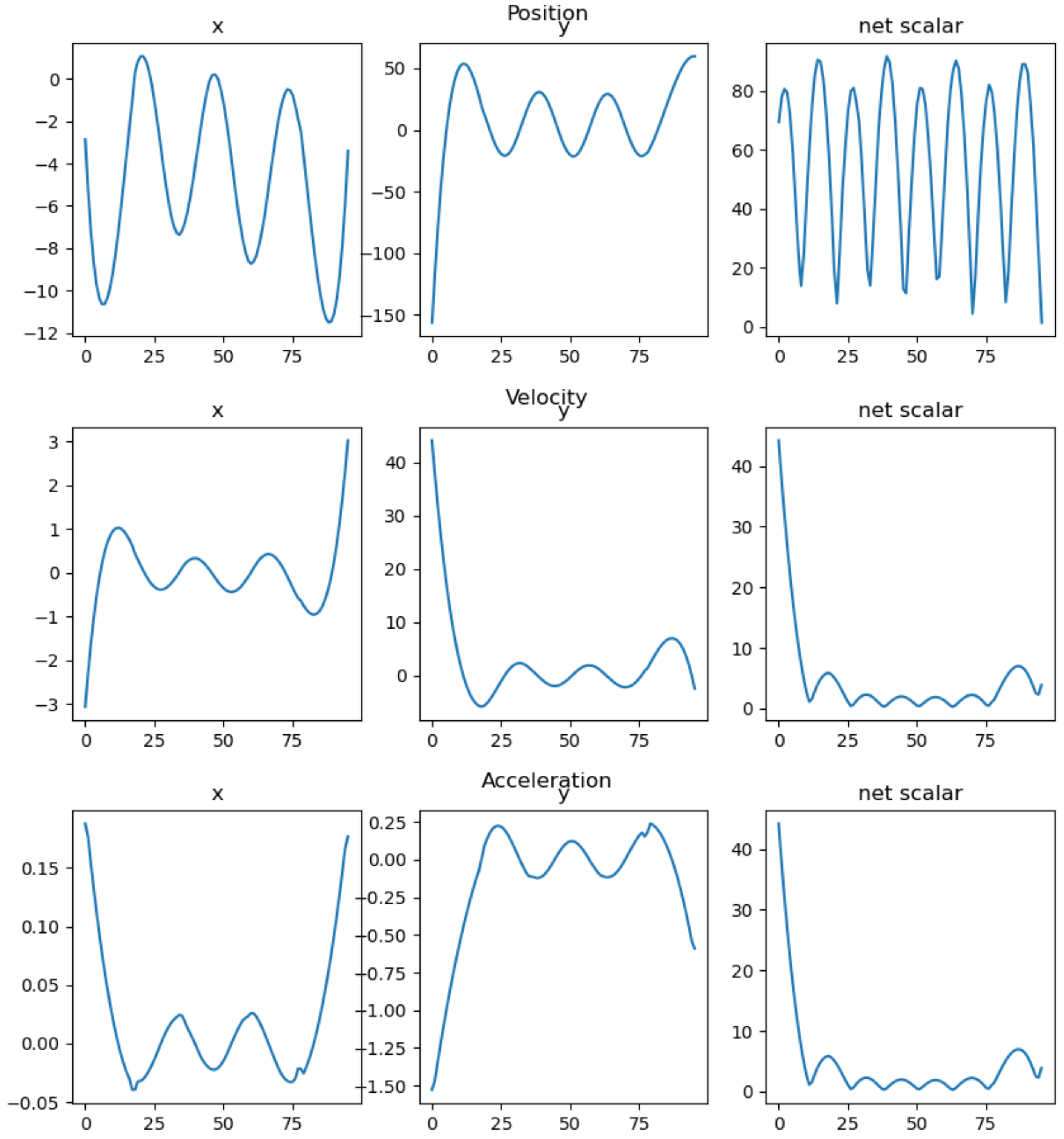
2 options:

1) OpenCV Tracking

2) Automatic NN tracking

(recognizes circular objects)

Video annotation

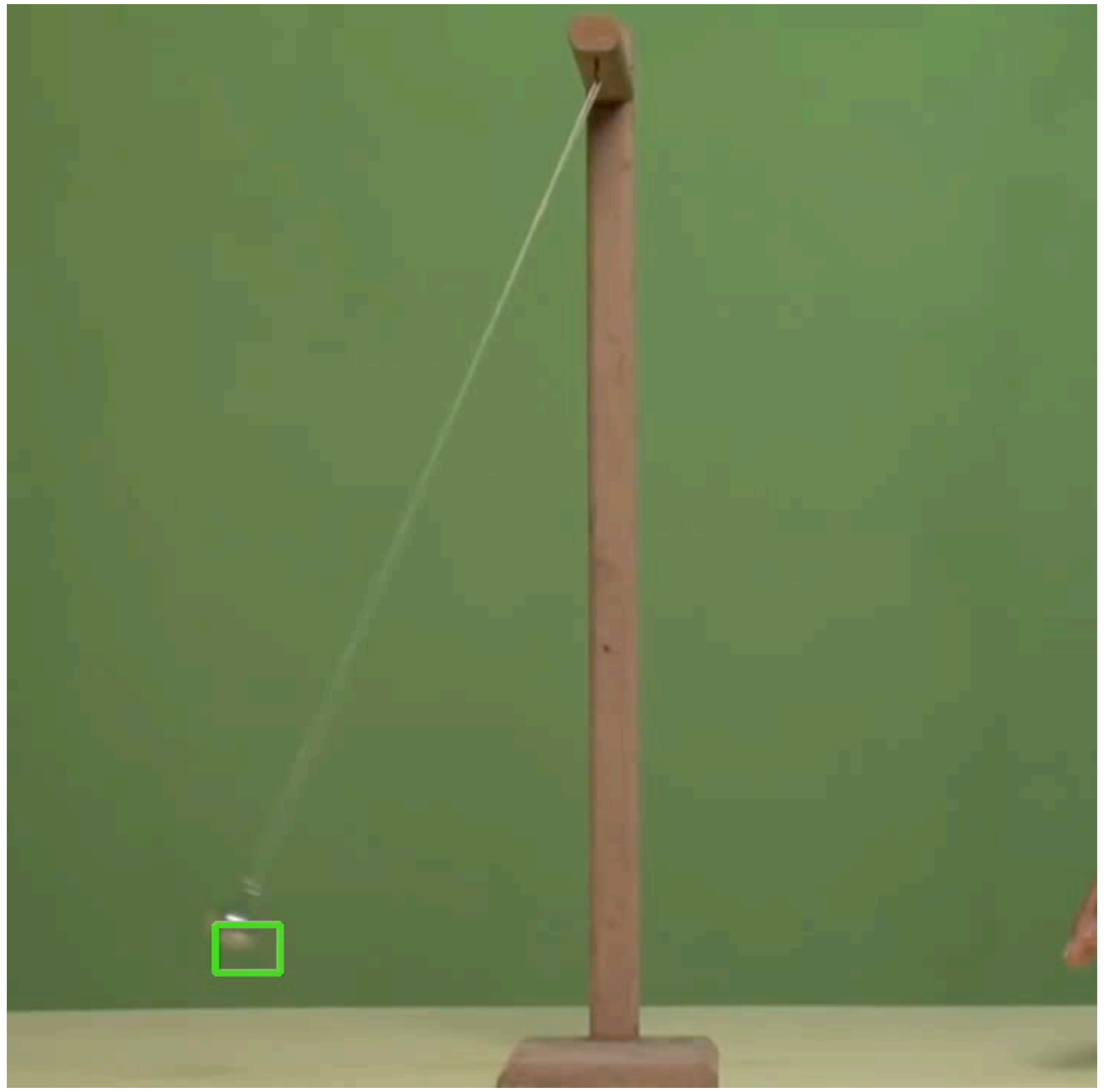


Trajectory extraction

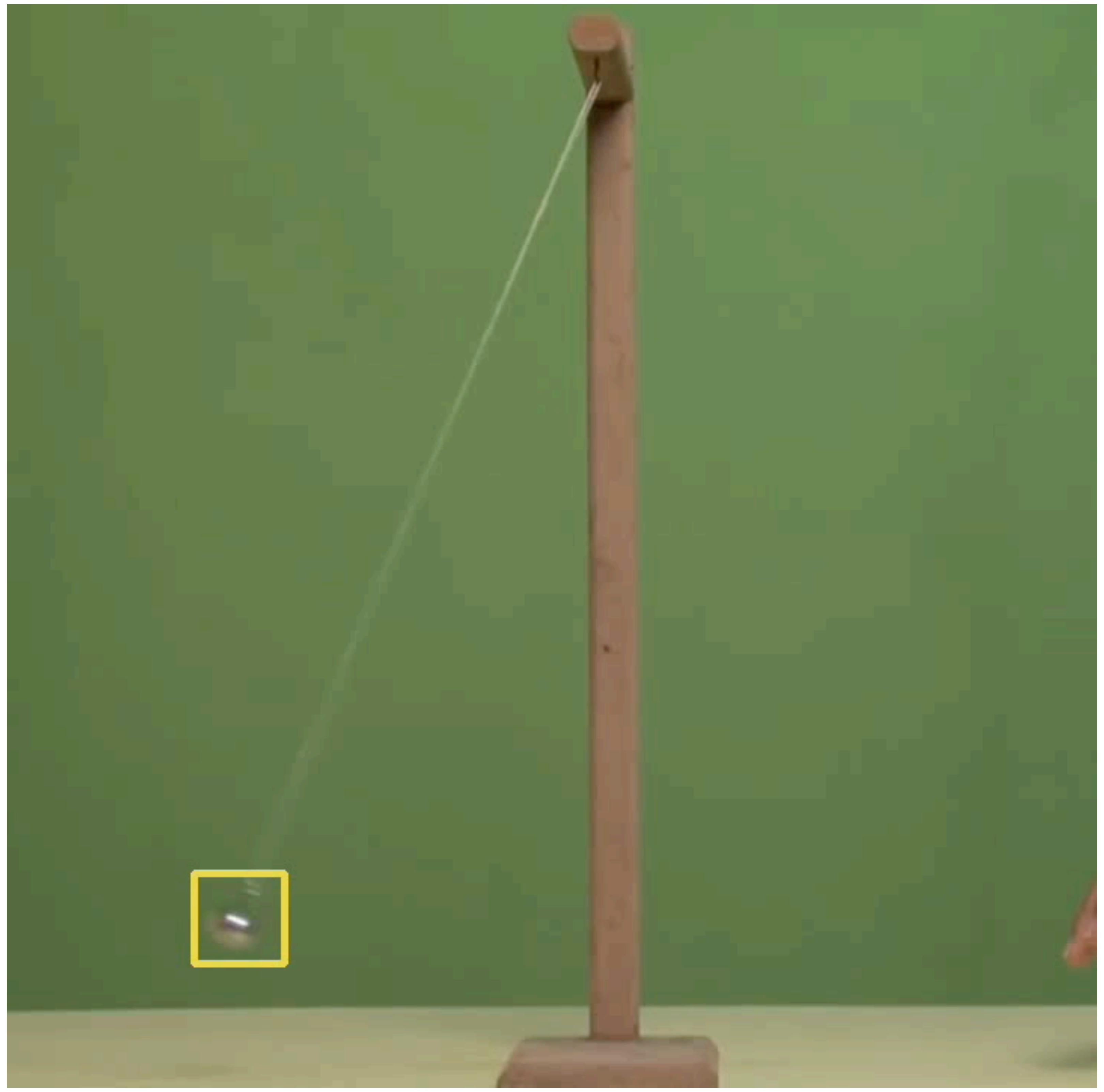
CSV + Recording + Plots

Lesson 3

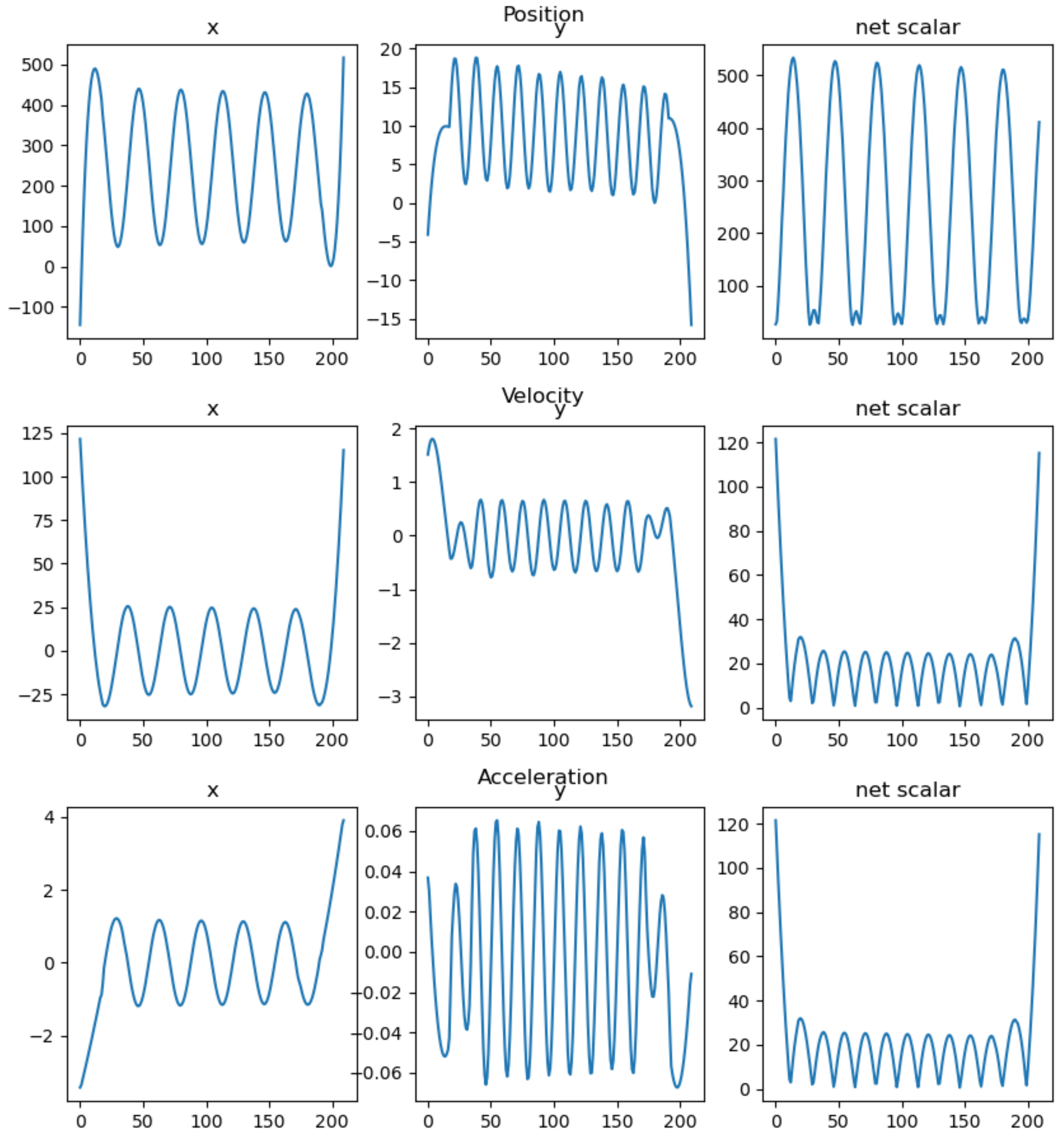
Not so automatic



Example of bad annotation



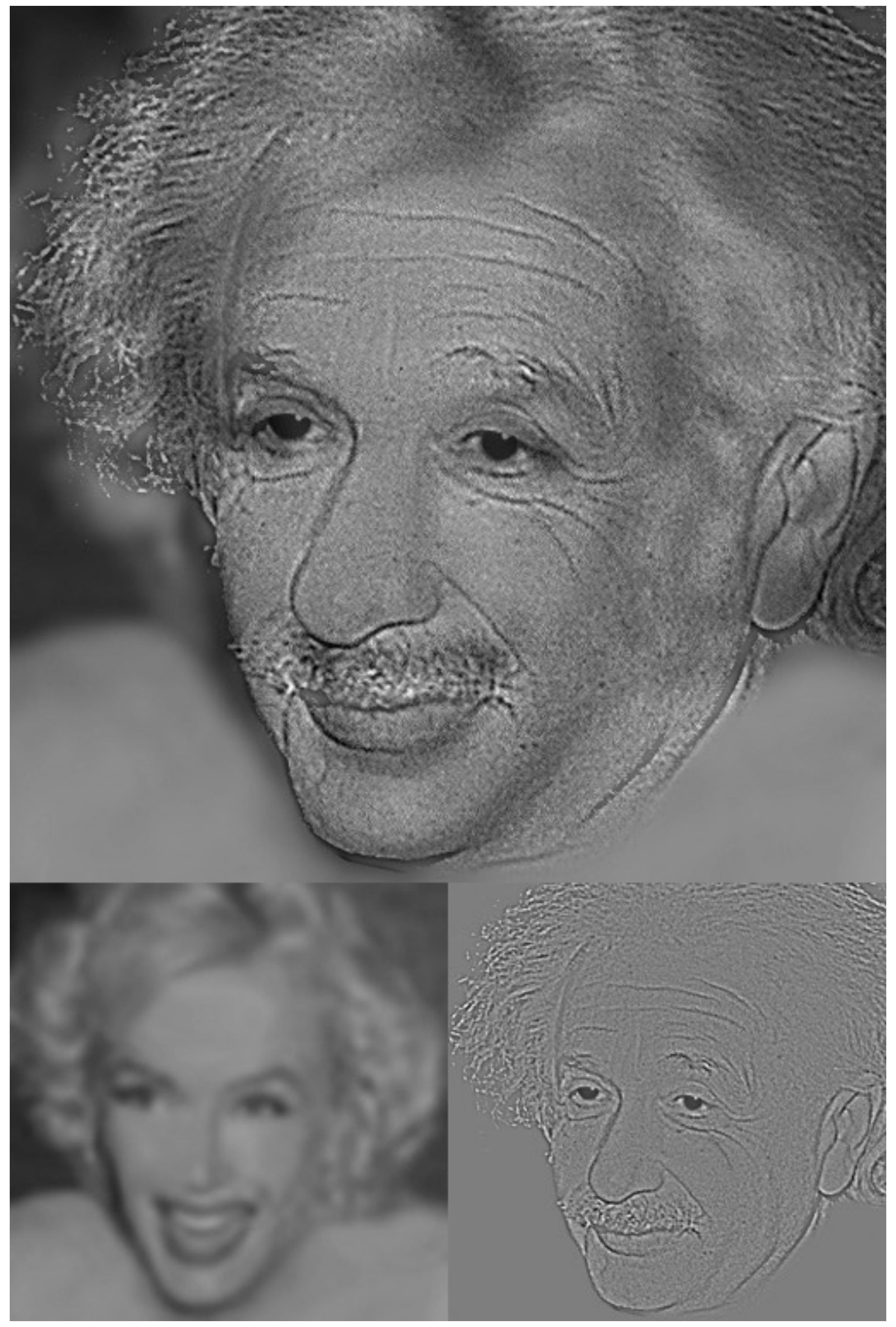
Good annotation



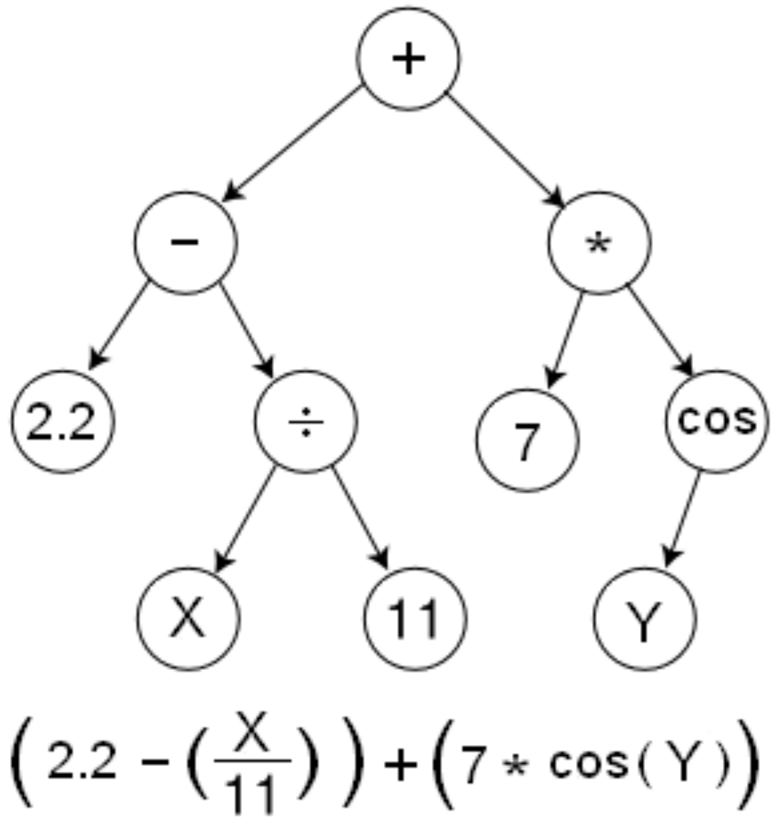
Trajectory for good annotation case

Mini-projects

1. Hybrid Images (After Notebook 1)



2. Combine with Symbolic Regression and Numerical Methods modules (After Notebook 2)



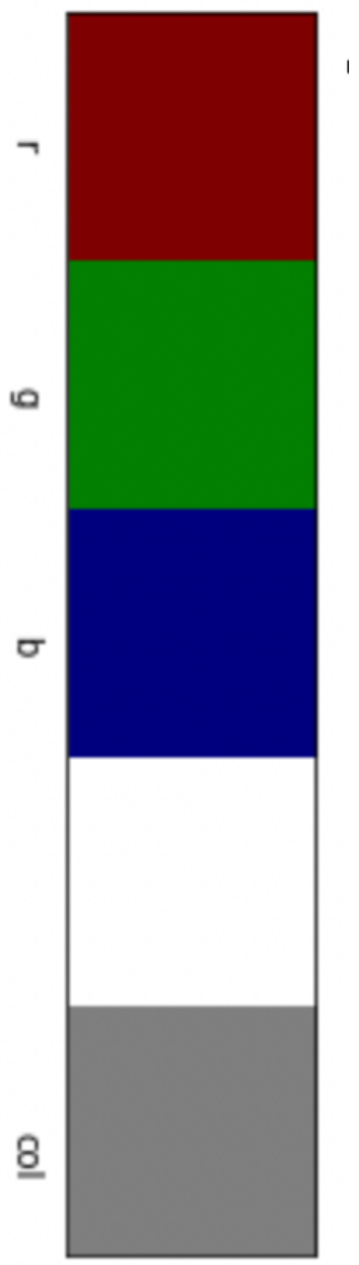
[Symbolic Regression](#)
- Joseph Dominicus Lap

$$\frac{1}{(\Delta X)^2}\begin{vmatrix} -2 & 1 & & & \\ 1 & -2 & 1 & & \\ & 1 & -2 & 1 & \\ & & 1 & -2 & 1 \\ & & & 1 & -2 \end{vmatrix}\begin{vmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \end{vmatrix} = \begin{vmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{vmatrix}$$

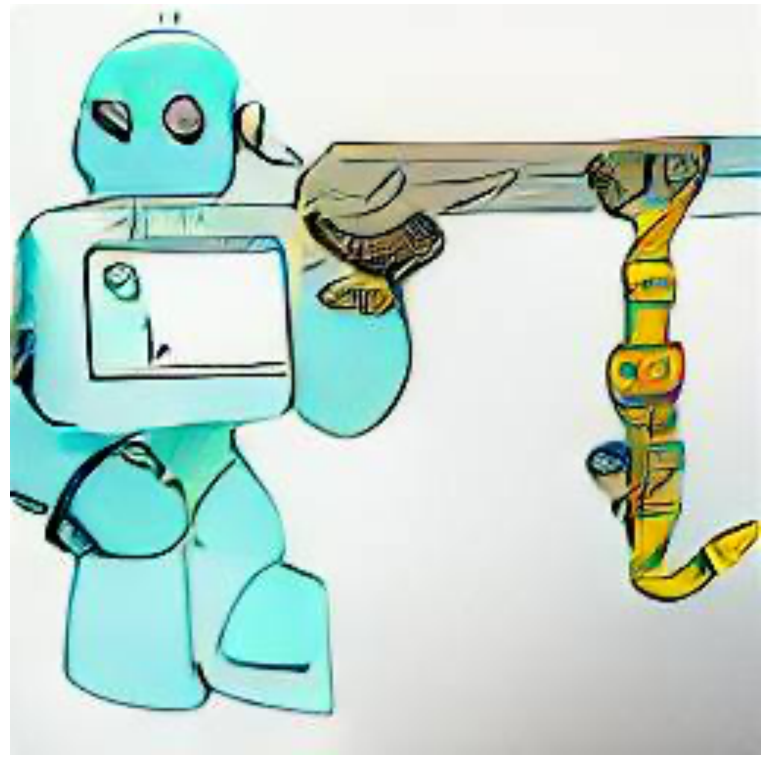
[Solving Differential Equations in Classical Mechanics with Neural Networks](#)
- Julie Butler

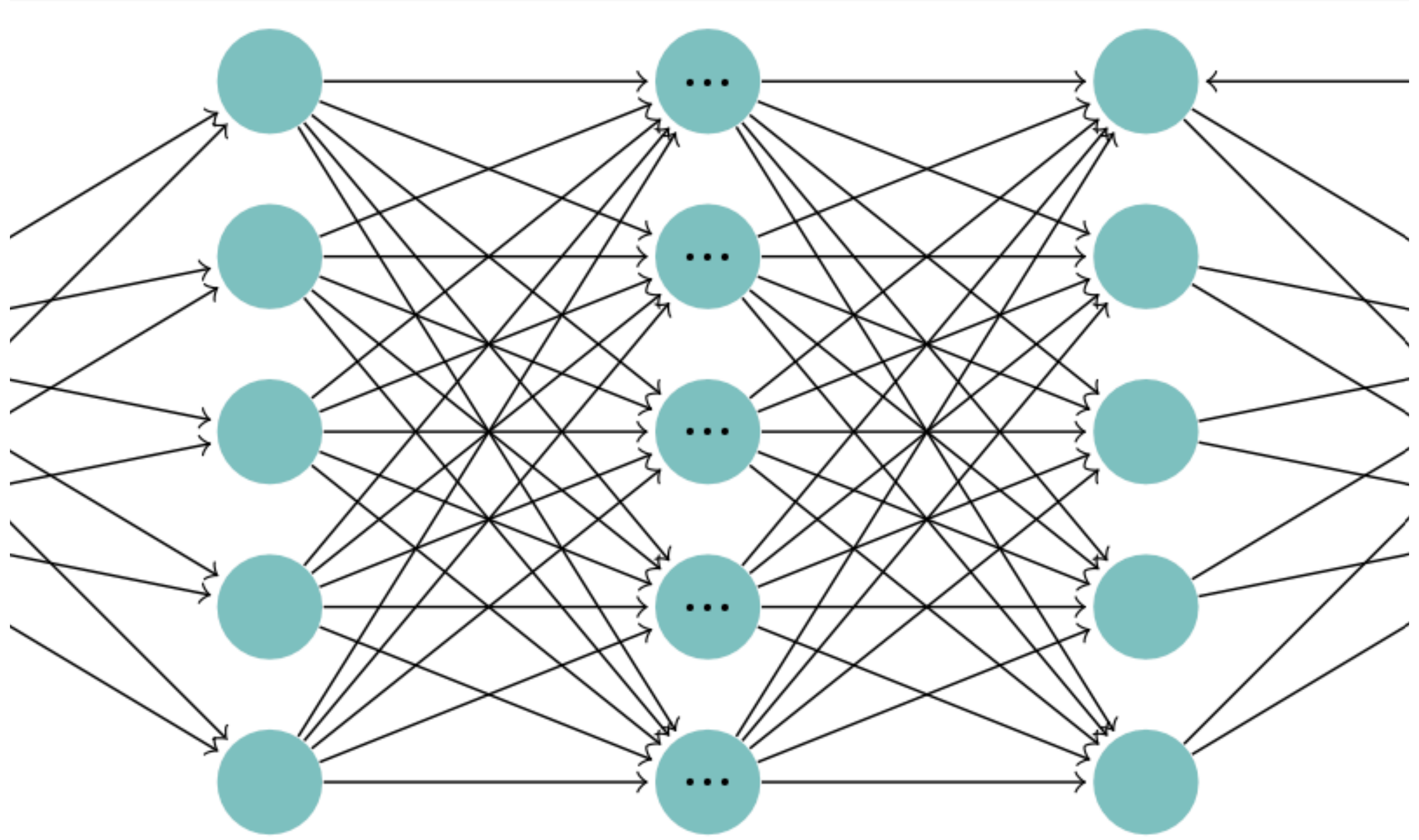
Supplementary:

Gentle Introduction to Neural Networks (with plumbing and colors)

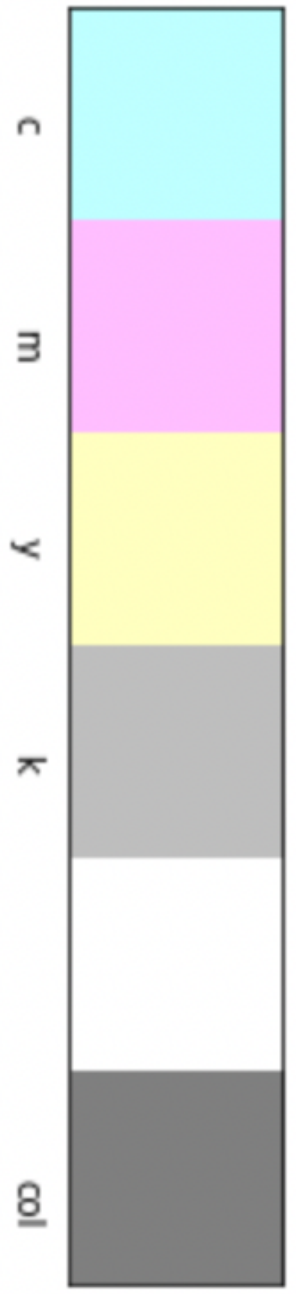


RGB





Neural Network
(Trainable Parameters)



CMYK

In module: [Learning the Schrödinger Equation]

Sample Lesson Plan

- Take home - Lesson 1: Image Manipulation (2 hours)
- In class - General discussion of requisite Linear Algebra
  (1 hour)
- Take home - Lesson 2 and Lesson 3: With included examples (1 hour)
- Mini-Project
  (2 - 4 hours)
- In lab - Lesson 2 and Lesson 3 - With videos of own experiments

Alternatives

- LoggerPro - Frame by frame annotation
- Physlets Tracker - Java based, Open source
- Vernier sensors - Need sensor hardware

Request for videos

- If you use this module in your lab course, can you also share some sample videos that your students take?
- Can be used to train a custom neural network specialised for lab experiments.

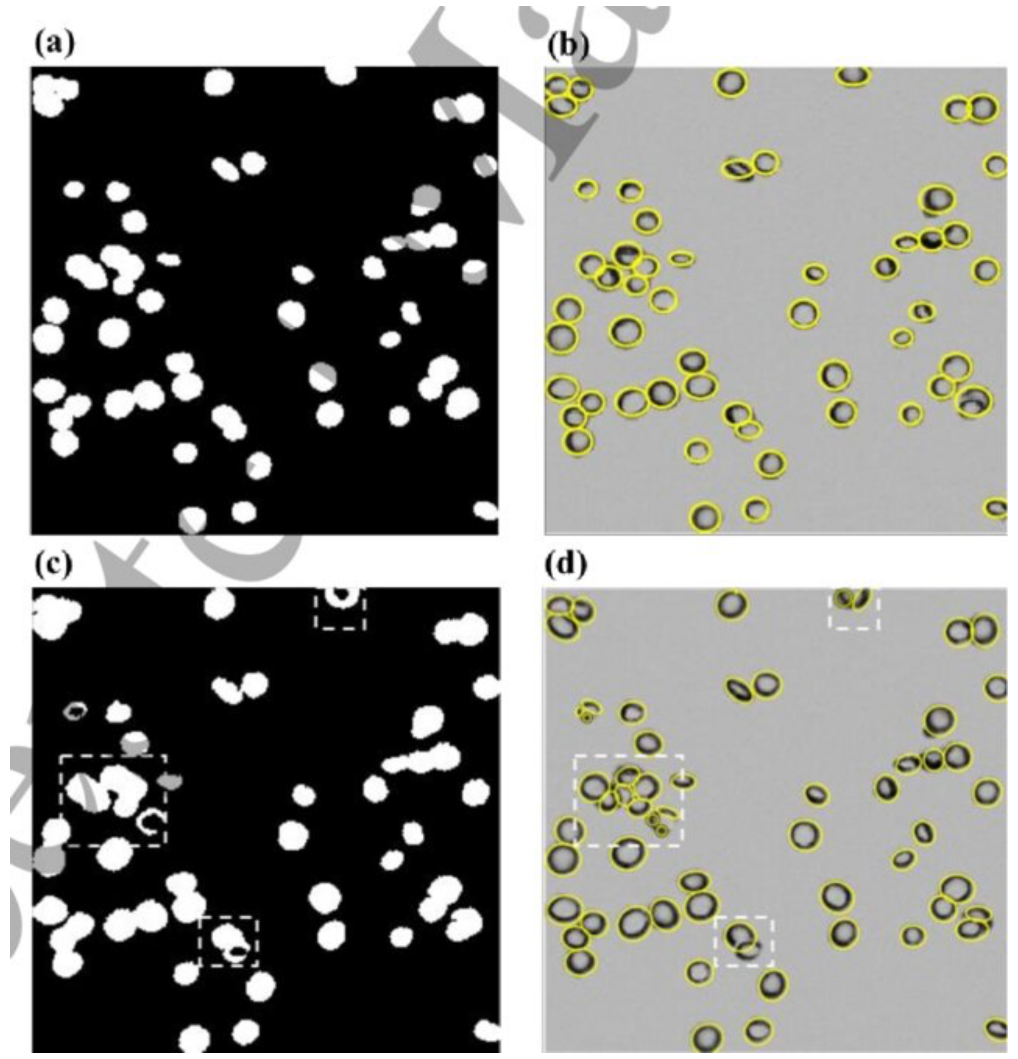
- Question: What tools are already being used in lab?

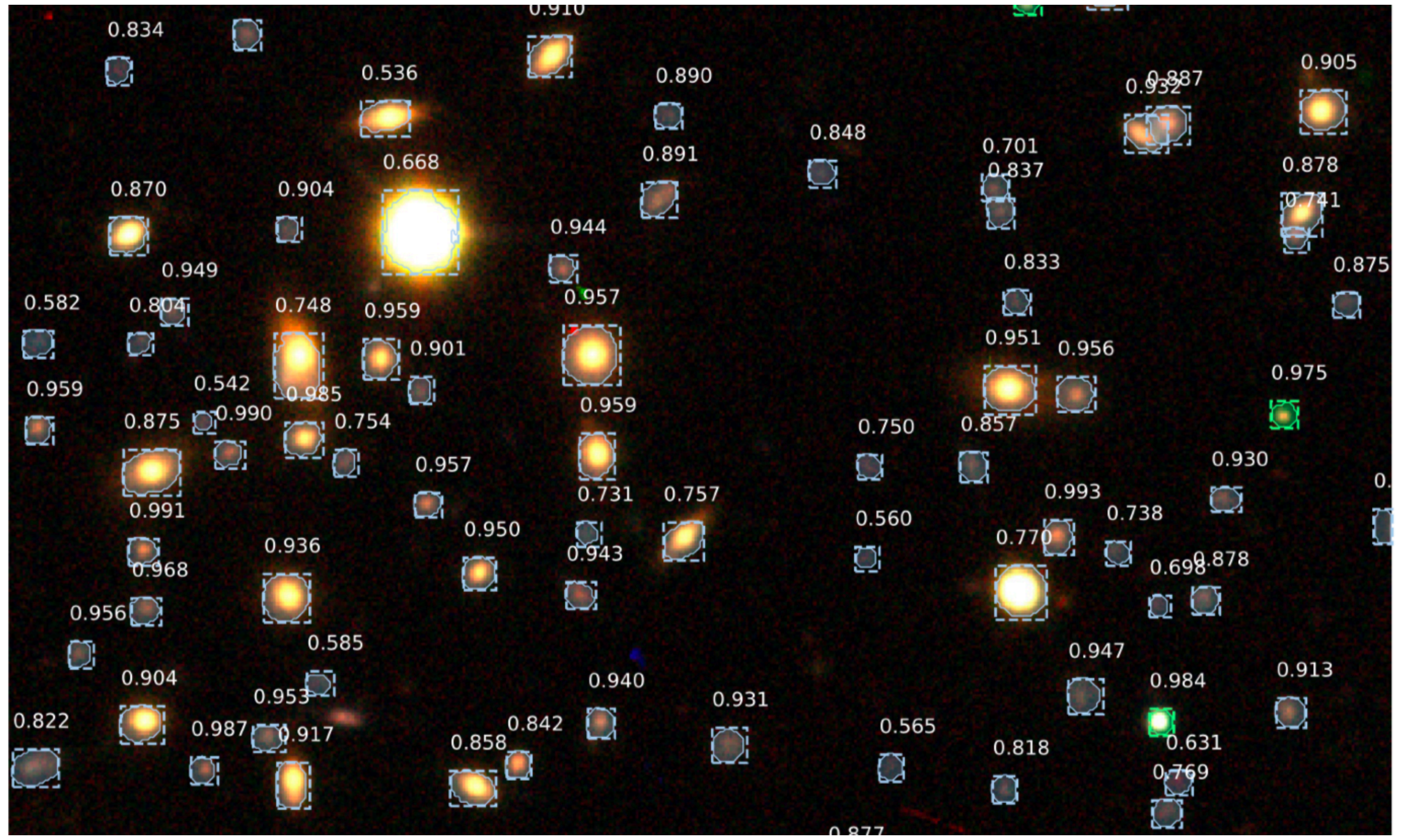
Please reach out on Github, Slack or at k.shah@hzdr.de.

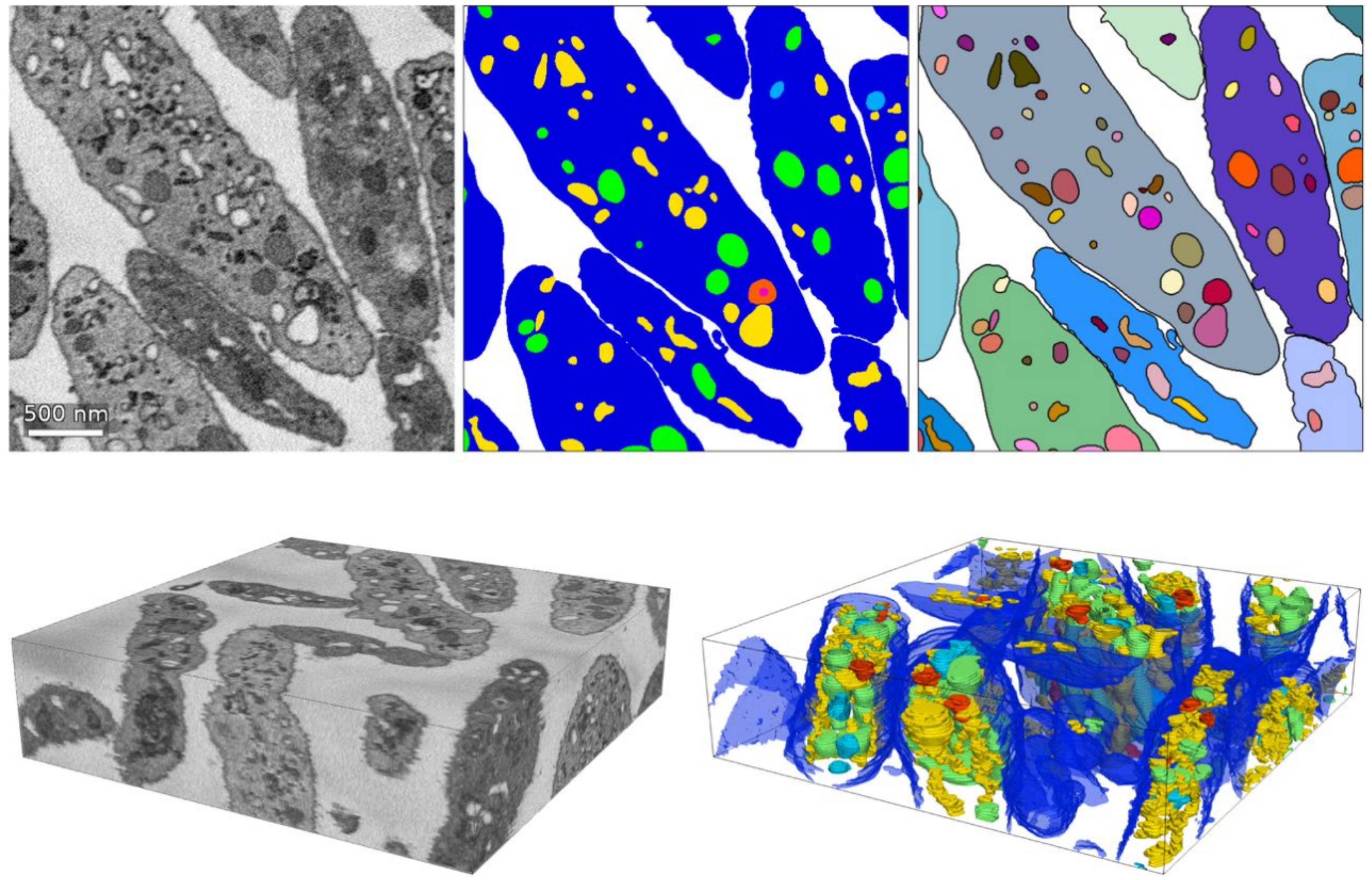
Conclusion

Conclusion

- Module can be used for a lab course
- Should be <u>actively modified by students</u> during labs
- Can be combined with DSECOP Modules: Symbolic Regression, Numerical Methods
- Computer vision can be useful in research too (eg image segmentation)



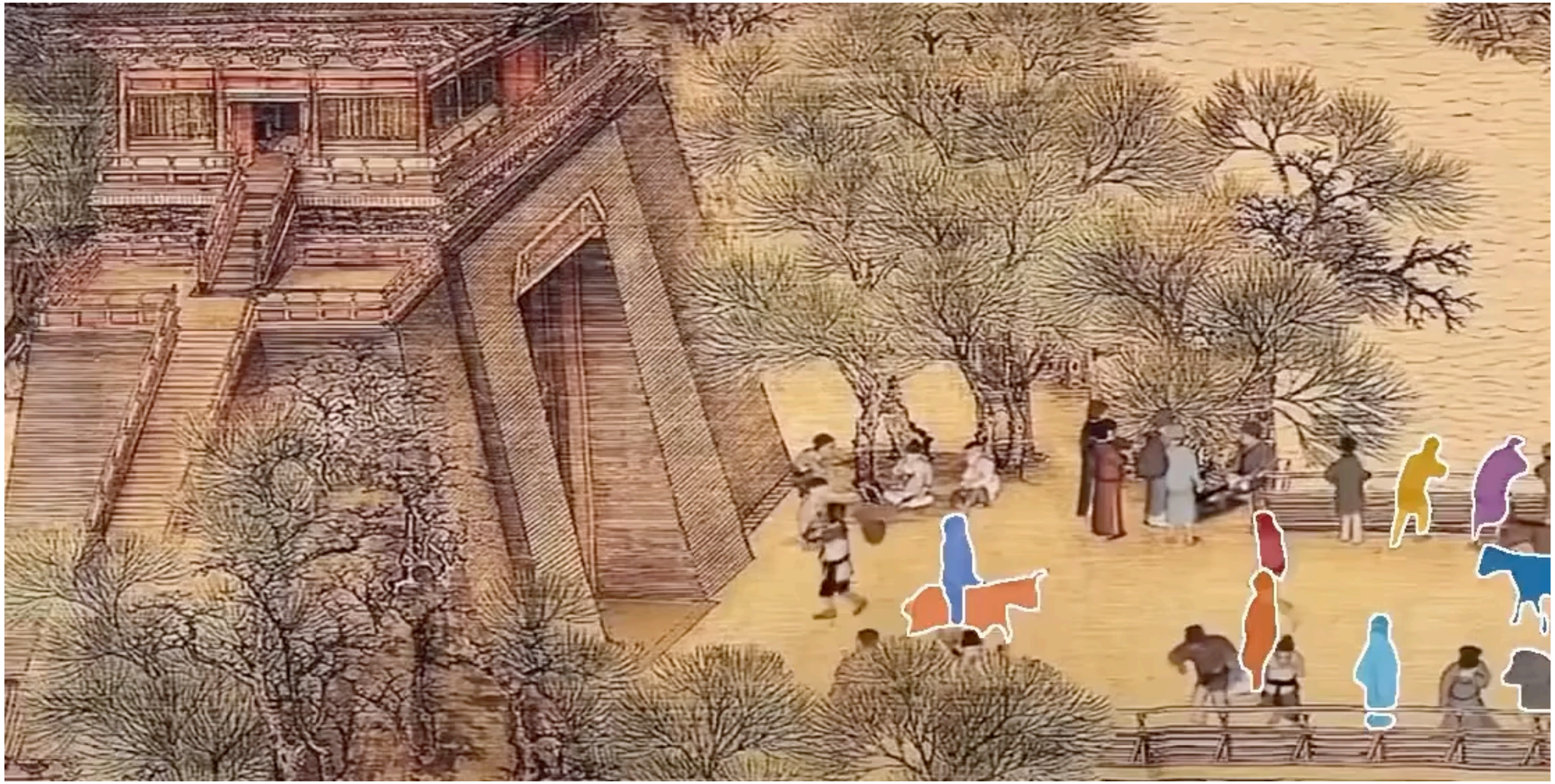




Please reach out on Github, Slack or at k.shah@hzdr.de.

Future work

- Fine-tuning Yolo network used here to detect common lab objects
- Advanced models: “Track Anything”



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Thank you!
Questions Comments Concerns?

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Feedback form:
https://bit.ly/DSECOP-feedback

Feedback

GitHub